

FINAL REPORT

Title: "ARTIFICIAL GRAVITY AS A COUNTERMEASURE OF CARDIOVASCULAR DECONDITIONING IN SPINAL CORD INJURY."

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PREFACE

An essential item in the development of this project was the availability of the artificial gravity simulator (AGS). The AGS was constructed through resources provided by another NASA GRANT (NAGW-1691) awarded in 1989 and was located at the Woodlands, Texas. At the termination of that grant in 1994, the AGS was dismantled and transferred to NASA Johnson Space Center of Houston. It took over two years for the AGS to be re-assembled and re-certified for use by NASA Johnson Space Center. During this time, our activity was limited to work with NASA employees to assist in the rebuilding of the apparatus, provide information needed to determine its safety, submit the proposal for approval and execution of the project at Johnson Space Center and to conduct the subject's recruitment process at The Institute for Rehabilitation and Research (TIRR). As a consequence of the non-availability of the AGS for two years, there was a considerable delay in implementing the various phases of the project. The recruitment of subjects comprised the study of eight healthy able bodied subjects and twelve subjects with spinal cord injury. After analysis of the data collected on these subjects, six of the healthy able bodied subjects and three of the subjects with spinal cord injury were found to qualify for the study. This report gives the results of four subjects only, two healthy able bodied and two spinal cord injured subjects because the period of the grant (1 year) and its extension (1 year) expired before additional subjects could be studied.

OBJECTIVE

The principal objective of this study was to conduct a series of experiments to demonstrate the feasibility of submitting spinal cord injured subjects to artificial gravity as produced by a short arm centrifuge (AGS), to determine their tolerance to it. This was done as a preliminary step toward the possible subsequent use of artificial gravity as a rehabilitative approach to the cardiovascular reconditioning of these subjects, whose capacity for muscular exercise, and therefore to stand up, is often severely limited.

Plan of study. The study was conducted in two phases.

Phase I. Consisted of administering a questionnaire, a physical exam and performing analyses of blood and urine. The results were submitted to the Johnson Space Center Aerospace Medical Board to obtain the waiver necessary to proceed with the study. Two more tasks in phase I were: To perform a tilt test and to familiarize the subject with the AGS. The tilt test on healthy able bodied subjects, provided by JSC, was performed by NASA personnel. After the tilt was performed the subjects were taken to the AGS laboratory and were explained how the test with the AGS would be performed the next time they would come to be tested. The subject was given a short run with the AGS to familiarize him with it.

Phase II. This phase consisted of the test with the AGS. The subject was tested several times at various G levels in order to find out what were his physiological responses and to assess his tolerance to acceleration. The results of the last test were analyzed only. The results obtained on healthy and spinal cord injury subjects are shown in the appendices. The steps of the test for subjects with spinal cord injury were the same as those used in the tests for healthy able bodied subjects.

METHODS

The subjects whose data are analyzed in this report are subject 1, NS, healthy able-bodied. Subject 2, ML1, healthy able bodied. Subject 3, MW, paraplegic L5. Subject 4, ML2, paraplegic T12. Data were collected on them through the following procedures:

The questionnaire, physical exam, and blood and urine samples test were done at the Johnson Space Center using well established procedures and analytical techniques. The physical exam included vital signs, skin, eyes, ears, nose, pharynx, neck, chest, heart, abdomen, extremities, neural and spinal observations. Also an ECG, an audiometry test and laboratory analyses were performed. The laboratory analyses included: white cell count, differential, urinalysis, blood chemistry profile, serum osmolality, lipid profile, and high density protein.

The head-up tilt test was performed with a tilt table. Continuing recordings were taken during three phases: in phase 1 the subject remained supine for 10 minutes; in phase 2 the table was tilted head-up 65° degrees for 10 minutes; in phase 3 the table was tilted back to horizontal and monitoring continued for 10 minutes more. The variables recorded were: thoracic impedance, stroke volume, heart rate, cardiac output, and ejection velocity index with the Medex apparatus; the arterial blood pressures were obtained with the Portapres apparatus from a finger and also with a manometer attached to an arm with a cuff at two-minute intervals. The figures utilized in the analysis and display of curves correspond to readings taken at one minute.

The centrifuge test consisted of placing the subject at the AGS and then start rotation at variable rpms to produce different G forces, that is, while in the AGS the head of the subject was directed toward the axis of rotation of the AGS and the feet were directed toward the periphery of the instrument's platform. The G forces were measured at the feet level. It was a condition established in the protocol that subjects would be submitted to not more than 1 G.

RESULTS

Tilt Test

The tilt test was performed on the subjects with spinal cord injury before they were submitted to the centrifuge test with the AGS.

The protocol of the tilt test was as follows:

- Subject supine on the tilt test table in the horizontal position for 10 minutes.
- Subject tilted head-up at 65° degrees for 10 minutes
- Subject back to supine in the horizontal position for 10 minutes

The variables continuously recorded in the three stages were: systolic (SBP) and diastolic (DBP) blood pressures, heart rate (HR), cardiac output (CO), stroke volume (SV), Peripheral resistance (PR), Thoracic impedance (TZ), ejection velocity index (EVI). The results are shown in appendices 1 and 2.

The profile of the changes in the variables observed in the subjects tested is described next. In assuming the head-up tilt there was an immediate increase in thoracic impedance (TZ) which was sustained during the whole period of tilt. In re-assuming the horizontal position, TZ returned to the pre-tilt level or remained a little elevated. This pattern was consistent in the two subjects, although the change in impedance was more prominent in subject (4 ML2) (approximately 3.0 ohms or 11%) than in subject (3MW) (approximately 1.6 ohms, or 5%)

Changes in TZ are considered to reflect changes in thoracic fluid volume. An increase in TZ reflects a decrease in thoracic fluid volume, whereas the decrease in TZ reflects an increase in thoracic fluid volume. The body fluid distribution in changing posture from horizontal to vertical and from vertical to horizontal is a primary effect of the change in the relationship

between the earth gravitational vector and the sagittal axis of the body. It makes sense, then, to relate changes in other circulatory parameters to the primary changes that occur in body fluid distribution.

Changes in stroke volume were opposite to changes in TZ. That is, an increase in TZ during tilt was accompanied by a decrease in stroke volume. Heart rate, changes in the same direction as TZ and it tends to compensate the change in stroke volume, so that cardiac output remains approximately the same or diminishes a little.

The effect of tilt on systolic and diastolic blood pressures was very modest. In both subjects the diastolic blood pressure showed a small increase, whereas systolic blood pressure increased a little in one of the two subjects and did not change in the other. Peripheral resistance increased in both subjects during the head-up tilt period.

The response to head-up tilt of these two subjects was not different from that generally observed in healthy able bodied subjects.

Centrifuge Test

The centrifuge test was performed with the AGS.. All the subjects, able bodied and spinal cord injured subjects, were submitted to the same protocol. The protocol consisted of:

1. Standing (able bodied) or sitting (spinal cord injured) for 5 minutes.
2. Supine rest on the AGS bed for 10 minutes.
3. Supine plus rotation of the AGS at 0.5 G for 5 minutes.
4. Supine plus rotation at 0.75 G for 5 minutes.
5. Supine rest for 10 minutes.
6. Standing (able bodied) or sitting (spinal cord injured) for 5 minutes.

The variables recorded were the same as those recorded in the tilt test, that is: systolic (SBP) and diastolic (DBP) blood pressures, heart rate (HR), cardiac output (CO), stroke volume (SV),

Peripheral resistance (PR), Thoracic impedance (TZ), ejection velocity index (EVI),

Response of the able bodied subjects

The results are displayed in appendices 3 and 4. During the AGS test, TZ exhibited the following pattern: TZ was high in the standing position, it decreased in adopting the supine position, it increased, although at a lower level than standing, during centrifugation, and increased again in standing to approximately the same level as in standing before the centrifugation.

The SV was lower in the standing position as compared with the supine position and centrifugation values, although there were marked oscillations and no detectable increase between supine and centrifugation values in one of the subjects (subject 2).

The HR, higher in standing, decreased during supine and centrifugation, but there was no difference between supine and centrifugation values.

The CO exhibited marked oscillations. In one of the subjects (1,NS) appeared to increase a little during centrifugation, whereas the other subject (2,ML1) did not show any change except marked oscillations as compared to standing.

The EVI during centrifugation seemed to increase a little in one of the subjects (1,NS) as compared to the values observed during standing and supine.

The arterial blood pressures (SBP and DBP) decreased a little in going from standing to supine, but there was no difference between supine and centrifugation values.

The peripheral resistance decreased during supine in comparison with standing values. Centrifugation values increased a little with centrifugation in comparison to supine values in

subject 2ML1.

Response of spinal cord injured subjects

The results are displayed in appendices 5 and 6. The pattern of TZ was as follows. TZ was higher in the sitting position before and after the AGS test, it decreased in assuming the supine position and increased during centrifugation.

Stroke volume (SV) increased in the supine position as opposed to sitting, but showed no changes with centrifugation.

The HR decreased during the supine position, but remained the same during centrifugation as compared to that of the supine position.

In one of the subjects (3,MW), CO did not change, whereas, in the other (4,ML2) increased during supine and centrifugation as compared to the sitting values.

EVI increased during supine and centrifugation as compared to the sitting values, but there was no difference between the supine and centrifugation values.

The arterial pressures (SBP and DBP) decreased both during supine and centrifugation, but there was no difference between supine and centrifugation values.

The peripheral resistance decreased from sitting to the supine position. It increased a little during centrifugation and went back to the pretest value after reassuming the sitting position.

Comparison between spinal cord injured and able bodied subjects

In the AGS test, the pattern of the response of TZ was practically the same in the able bodied and spinal cord injured subjects. The SV response was also similar, but both spinal cord injured and

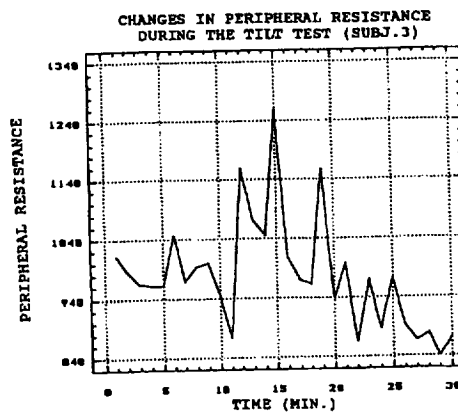
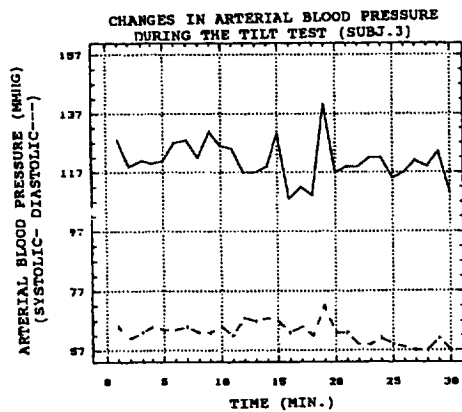
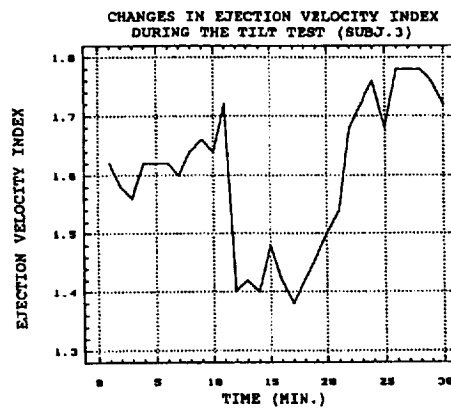
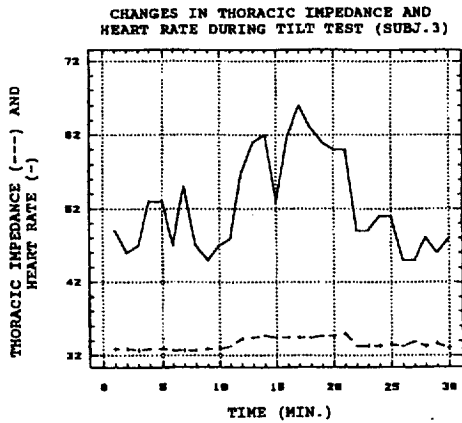
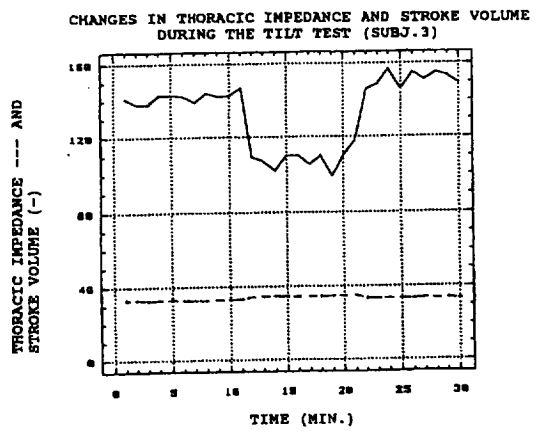
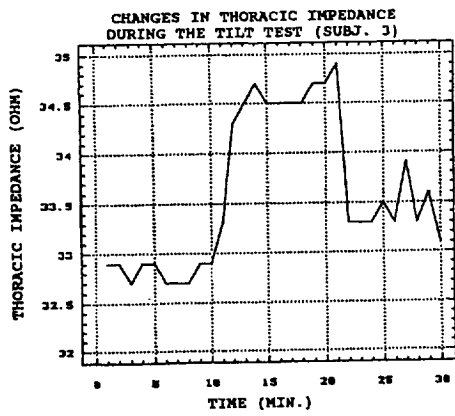
able bodied subjects exhibited marked oscillations, particularly during centrifugation. The HR changes were also similar in spinal cord injured and able bodied subjects and CO exhibited individual changes, with marked oscillations, which were different among subjects, both comparing able bodied and spinal cord injured among themselves. The same can be said about the observed EVI changes, there was no pattern. The pattern in arterial blood pressures (SBP and DBP) and peripheral resistance changes was similar in both groups of subjects.

This comparison permits to conclude that the response to the AGS was qualitatively the same in spinal cord injured and able bodied subjects.

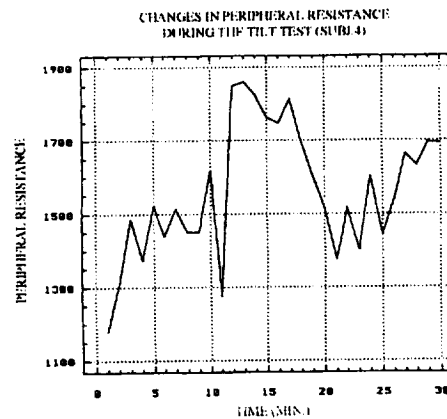
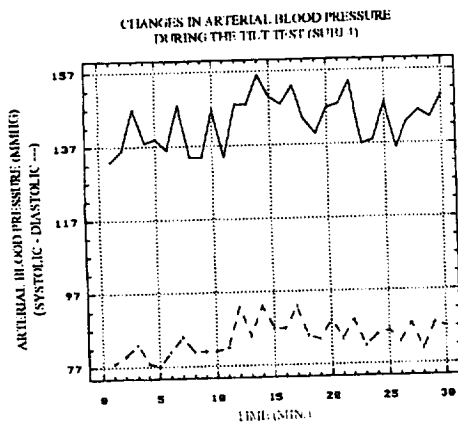
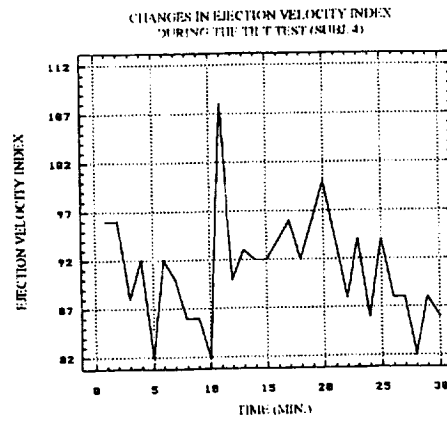
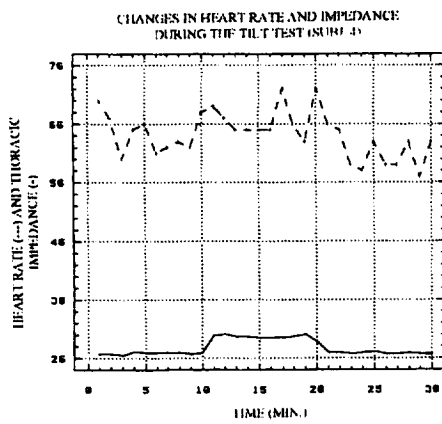
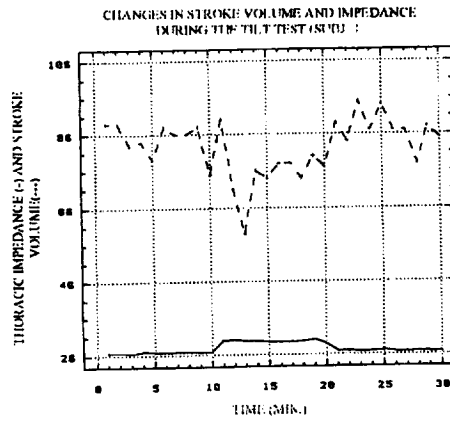
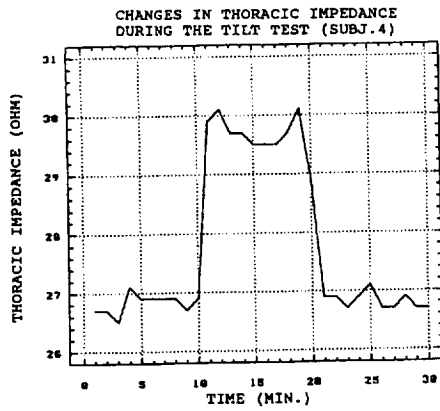
Comparison tilt to AGS test responses

In changing position from horizontal to vertical there is a change in the relationship between the earth gravitational vector and the sagittal axis of the body which causes a displacement of body fluids from the upper to the lower part of the body. When a subject is submitted to the positive G force created by rotating the AGS, a displacement of body fluids from the upper to the lower part of the body should also occur. One should expect, then, the response to the tilt test and the response to the AGS test to be similar. This is indeed what occurred in the spinal cord injured subjects who were submitted to both the tilt and the AGS tests. Tilt and centrifugation produced similar effects on TZ, SV, HR, EVI, SBP and DBP and PR. It is clear, however, that the centrifugation effect was somewhat masked by the opposite effect of the supine position. The intensity of the G forces utilized in these experiments was too small to show always the opposite effect of centrifugation to the effect of posture.

APPENDIX 1

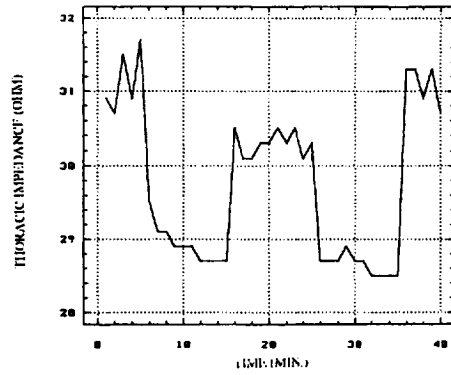


APPENDIX 2

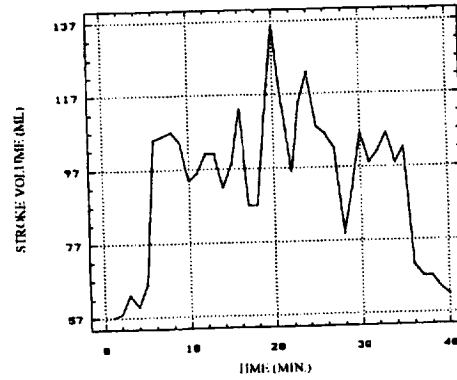


APPENDIX 3

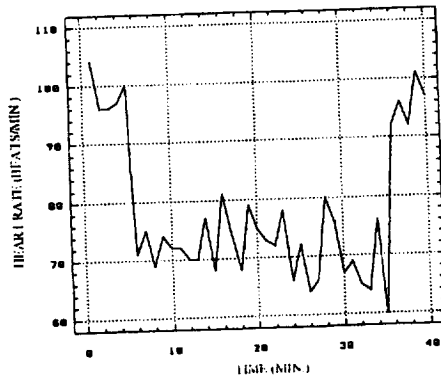
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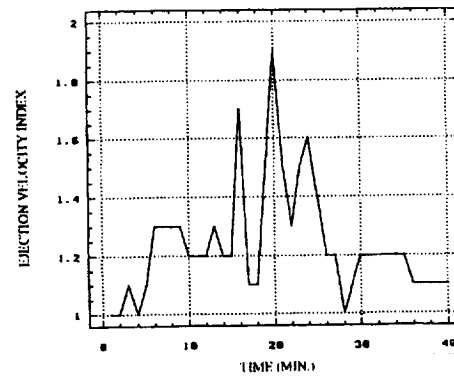
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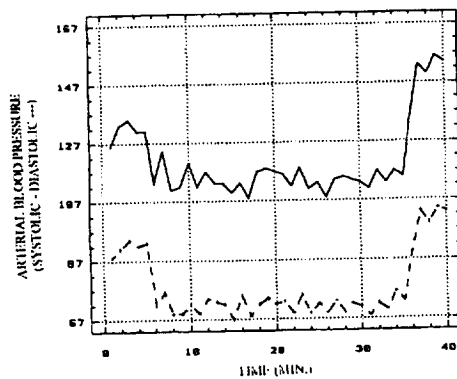
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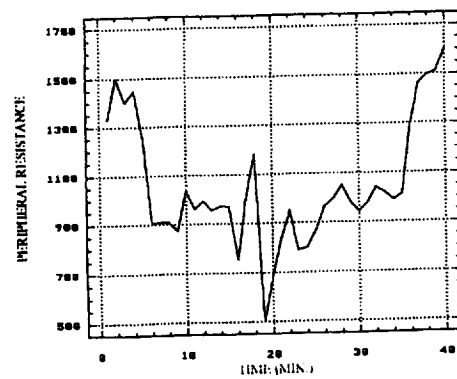
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DURING AGS TEST (SUBJ. 1)

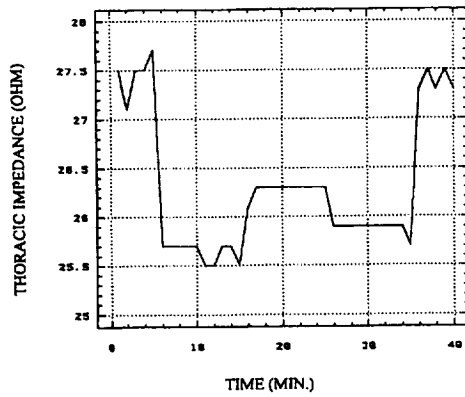


CHANGES IN PERIPHERAL RESISTANCE
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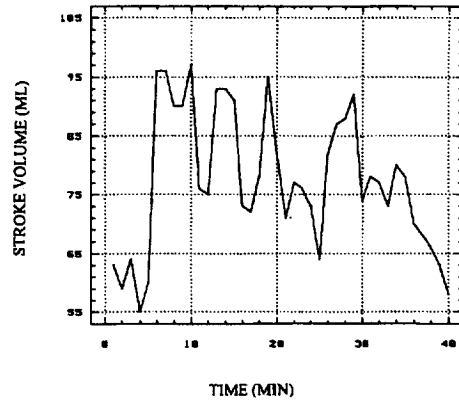


APPENDIX 4

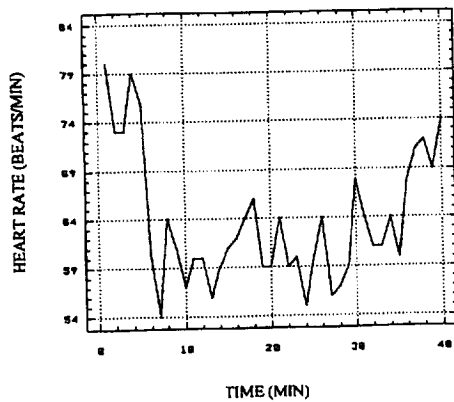
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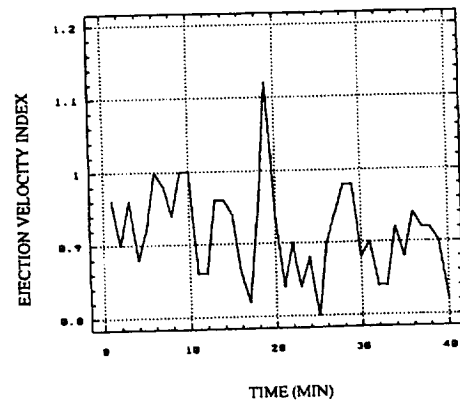
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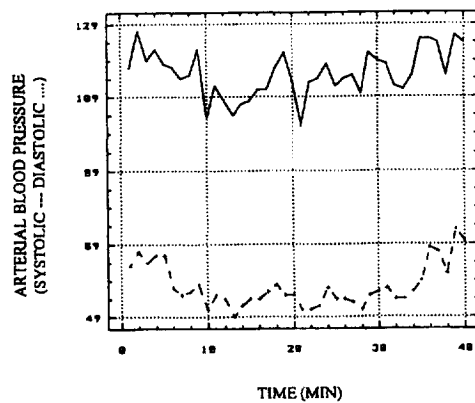
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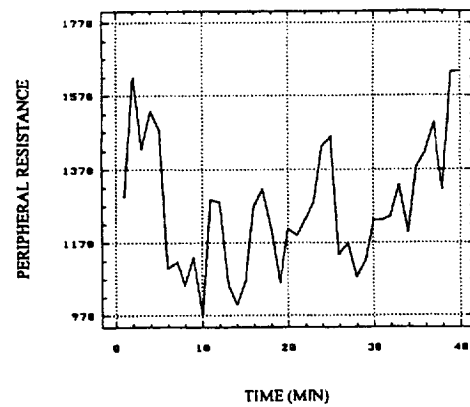
CHANGES IN EJECTION VELOCITY INDEX
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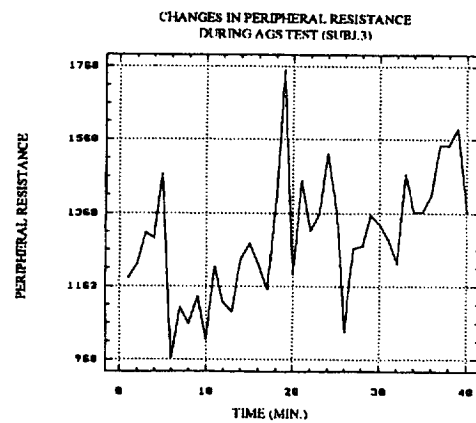
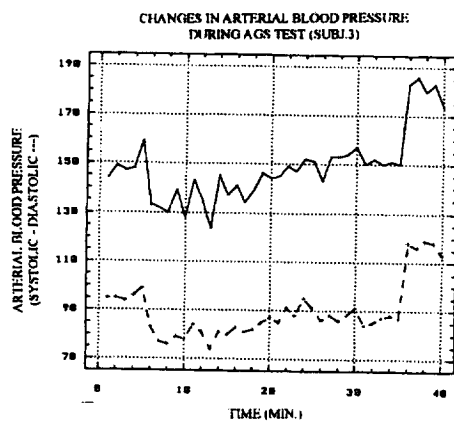
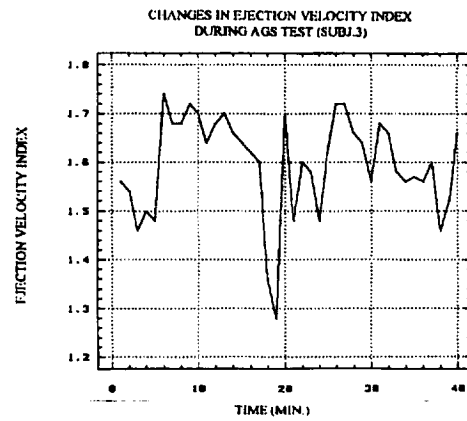
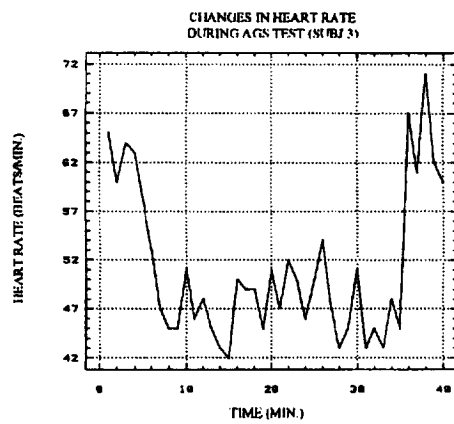
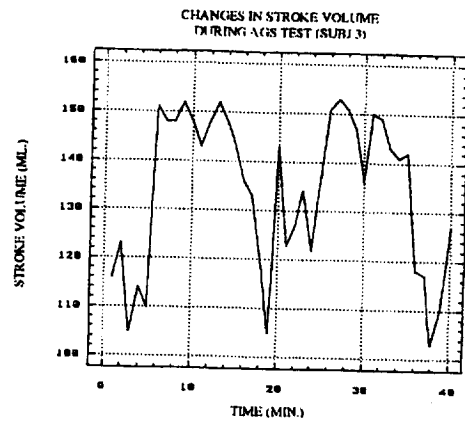
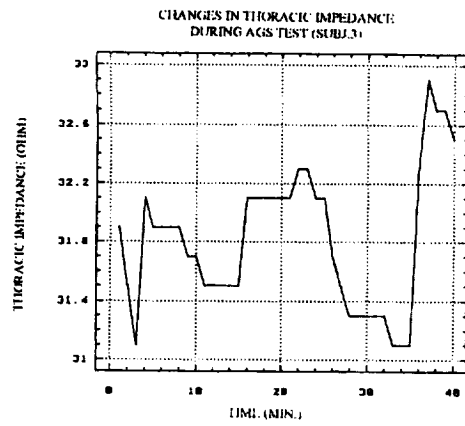
CHANGES IN ARTERIAL BLOOD PRESSURE
DURING THE AGS TEST (SUBJ. 2)



CHANGES IN PERIPHERAL RESISTANCE
DURING AGS TEST (SUBJ. 2)

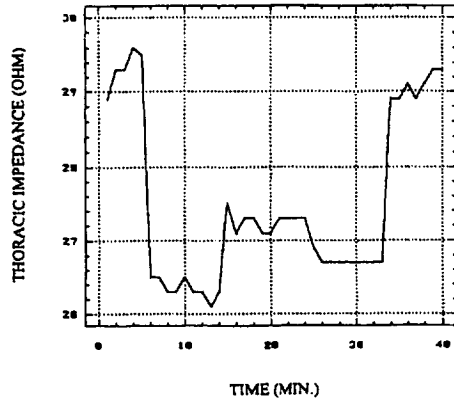


APPENDIX 5

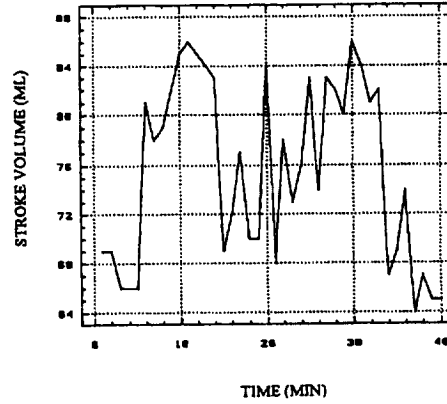


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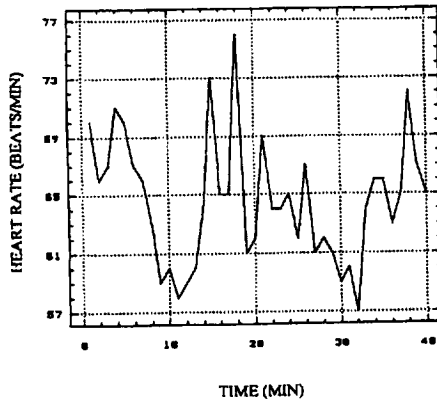
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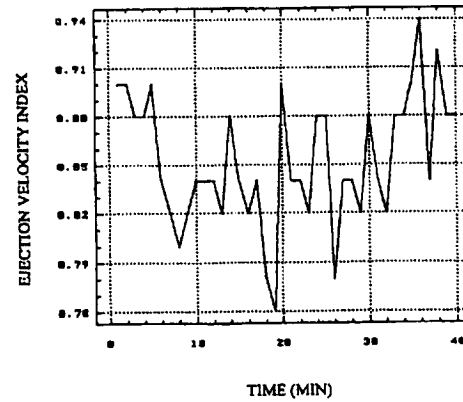
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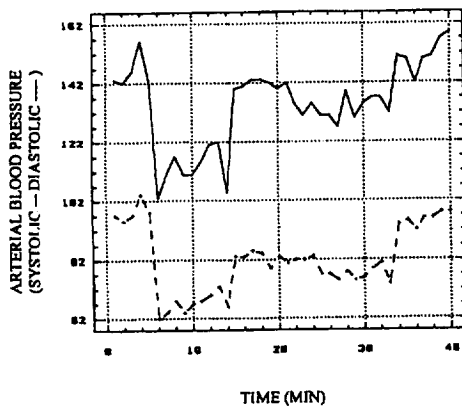
CHANGES IN HEART RATE
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CHANGES IN EJECTION VELOCITY INDEX
DURING THE AGS TEST (SUBJ. 4)



CHANGES IN ARTERIAL BLOOD PRESSURE
DURING THE AGS TEST (SUBJ. 4)



CHANGES IN PERIPHERAL RESISTANCE
DURING AGS TEST (SUBJ. 4)

